

Development of Urban Land Use Model to Compare Transit-Oriented and Automobile-Oriented Cities

Kazuhiro NOMURA, Gunma National College of Technology, Maebashi, 371-8530 Japan
(nomura@cvt.gunma-ct.ac.jp)

Hiroataka KOIKE, Utsunomiya University, Utsunomiya, 321-8585 Japan
(koike@cc.utsunomiya-u.ac.jp)

Akinori MORIMOTO, Utsunomiya University, (morimoto@cc.utsunomiya-u.ac.jp)

Summary

This study is an attempt to develop a simple simulation model that can compare the differences between automobile-oriented and transit-oriented cities, and clarify the difference between city forms by transportation modes. Following a theoretical model development, a series of simulation runs are tried. The model allocates people who commute to CBD from residential zones along a transportation corridor. As a result of many simulation analyses, it is shown that automobiles need much more traffic space in comparison with the transit as is shown by the proposed traffic space ratio both in CBD and along the corridor.

1 Introduction

Majority of urban activities in local cities in Japan with population under half a million are heavily dependent upon automobile transport, and it is a great uncertainty whether these cities continue automobile dependency as is now, or change to promote the utilization of public transit systems as alternative transport modes. Recently, as is found in the SACTRA report (Ref. 1) and other studies, there are many discussions on the effect of induced traffic as the result of road construction and improvement. It is often observed that road improvement aiming at the reduction of congestion resulted in the further aggravation of traffic jam due to induced traffic. It is called Downs-Thomson paradox (Refs. 2, 3). Now there is a necessity to develop a new transportation planning method to deal with such problems as whether the transit system development is effectively promoted by stopping the road improvement, or how to measure or forecast induced traffic volume. Sarker et al. (Ref. 4) have found that the transit utilization is high in the city where the road improvement level is low by using the gap index for 29 cities in Japan. But it has not fully explained the theoretical background. Kenworthy et al. (Ref. 5) have shown that the population density of a city is closely related to whether the city is transit-oriented or automobile-oriented, but the theoretical aspect has not been sufficiently clarified. Although their studies offered useful knowledge to those who try to promote transit system development, they cannot satisfactorily explain the reason why a city with high density and with a large gap index has higher level of transit utilization. It is necessary to clarify the theoretical aspect of why and how much these factors influence on urban forms, in order to use these indices for the practical and strategic urban planning tools. It is an inevitable path to overcome the problem in order to convince citizens who are so accustomed to the convenience of automobile and the strong road construction lobbies with powerful political influence in the local government in Japan.

2 Basic Framework of the Proposed Model

Automobile transport capacity is more flexible than transit, because it can vary depending on the number of highway lanes. However, the increase of number of lanes toward CBD as destination will decrease the available land area in CBD. In addition, parking space required to accommodate concentrating automobiles in CBD further decreases available floor space in CBD.

Thus, the space allocation mechanism for automobile transport is more complicated than transit. In this section, the proposed model framework is described by showing an analytical method, which examines how much automobile transport capacity exists based on the land use index assuming that there is enough demand to fulfill the supply of transportation capacity.

(The formulation)

When automobile occupancy rate is assumed to be one person per car, it is possible to obtain CBD floor space Y according to the following equation.

$$Y = A \cdot (1 - X) \cdot K \quad \text{--- (1)}$$

Where: X =CBD road rate, A = CBD area (constant value), K =CBD floor area ratio, M =per capita floor space (constant value).

Therefore, the number of potential commuters P is shown in (2). And, it is possible to obtain X by equation (3), where the number of traffic lanes necessary to achieve P is set to be $L(p)$.

$$P = Y/M = [A \cdot (1 - X) \cdot K] / M \quad \text{--- (2)}$$

$$X = (2 \times L(p) \times W) / LX \quad \text{--- (3)}$$

$$A = LX \times LY \quad \text{--- (4)}$$

Where, W =the width of a traffic lane, LX =the width of CBD, LY =the length of CBD By substituting (3) for (2), we can obtain (5).

$$M \cdot P = A \cdot (1 - X) \cdot K = A \left[1 - \frac{2 \cdot L(P) \cdot W}{LX} \right] \cdot K = LY [LX - 2 \cdot L(P) \cdot W] \cdot K \quad \text{--- (5)}$$

It is possible that we obtain largest commuter number that corresponds to the CBD floor area ratio by (7), where the number of traffic lanes is assumed to be a real number and is calculated here for simplification in (6).

$$L(p) = P / BC \quad \text{--- (6)}$$

$$P = A \cdot K / \left(M + 2 \cdot LY \cdot \frac{W}{BC} \cdot K \right) \quad \text{--- (7)}$$

Where: BC = traffic capacity where a certain headway is assumed.

If there is no constraint on the road rate in CBD or on number of traffic lanes, it is possible to obtain the maximum number of commuters in proportion to CBD floor area ratio and size of CBD from equations (5) or (7) above. In the following proposed model, P is obtained by assuming CBD road rate as constraint, and by introducing the residential zones along transportation corridor as the hinterland which is the origin of commuter trips. Needless to say, it has been assumed that the number of traffic lanes takes an integer value.

3 Proposed Model and Trial Conditions

Based on the idea as was described in the previous section, we tried to propose an urban land use model that can compare between automobile-oriented and transit-oriented cities, and clarify the difference between city forms by transportation modes. The model proposed here is a simulation model with a simple structure, which allocates people who commute to CBD from residential zones along a transportation corridor starting from the zones closest to CBD then continue to allocate in the subsequent adjacent zones until the maximum number of CBD employees is allocated. The input data to the model are, commuting time upper limit, corridor transportation modes (automobile or transit), basic unit of parking lot area, etc., and main outputs are, number of catchments zones, maximum number of CBD employment, number and length of automobile lanes or transit lines in transportation corridor and traffic density. The

model has the following characteristics: 1) It is possible to compare cities according to the corridor transportation modes, and 2) The corridor space is based on the braking stop distance in proportion to the design speed as is discussed by Bruun and Vuchic (Ref. 6).

The trial simulation is carried out under the following conditions.

- 1) The basic unit area of activity sphere used in the model for CBD and residential area is a rectangle of 1000m long (the corridor perpendicular direction) by 100m wide (the corridor parallel direction). It is also assumed that the center of the rectangle area is connected to a transit station or an intersection along the corridor with regular interval (see Figure 1).
- 2) The mean access times is 1 minute to the intersection by the automobile from the activity sphere, and mean access time is 5 minutes on foot to the transit station, assuming the automobile speed of 30 km/h and walking speed of 6 km/h. The corridor length is a difference between commuting time upper limit and total of access time in residential area and CBD (see Table 1).
- 3) The running speed (including the time for boarding and alighting) of the automobile in the corridor was set to be 30 km/h, and the transit speed is 20 km/h. Occupancy of the automobile is 1 person/vehicle, and the transit capacity is 30 persons/vehicle
- 4) The road rate for each activity sphere is 20%, and CBD floor area ratio for the business application is given as exogenous value, the residential area floor area ratio is set to be 100%.
- 5) The floor space per 1 person in CBD was set to be 20 square meters, and the floor space per 1 person in residential area was set to be 100 square meters. For simplification, all residents are assumed to commute to CBD (the number of commuters in an activity sphere is 800 persons each).
- 6) The basic unit of a parking lot in CBD was set to be 20 square meters per vehicle. Parking lot area in the residential area is included in the floor area per person.
- 7) The transit line is single track per direction. Commuter demand from a residential zone is obtained by the difference from the remaining transportation capacity, if the number of transit trains exceeded the permissible level. For automobile, the number of traffic lanes was calculated by adding a traffic lane within the range not exceeding the CBD road rate. The calculation method of a commuter demand is similar to the transit.
- 8) The headway that determines the capacity of a transportation mode was set to be 60 and 120 seconds for transit, and for automobile, the headway is set equal to running speed.
- 9) Commuting time upper limit to CBD was made to be 15, 30, and 60 minutes, and CBD floor area ratio were set to be 200, 300, and 400%. The lane width for transit and automobile are set to be 3.5 m/ lane for simplification.

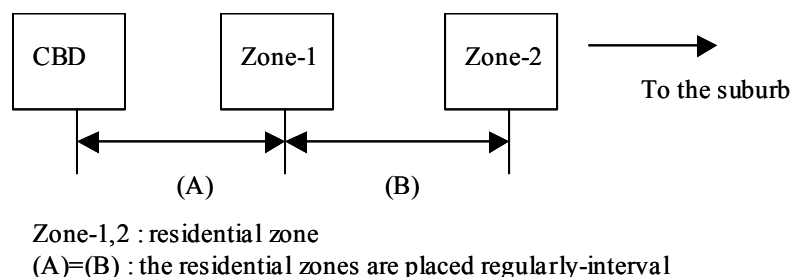


Figure 1. Basic Concept of the Proposed Model

Table 1. Corridor Length and it's Travel Time according to the Commuting Time Upper Limit

		Commuting time upper limit			Access time (C)	Egress time (D)
		15 minutes	30 minutes	60 minutes		
Car	(A)	6500 m	14000 m	29000 m		
	(B)	13 minutes	28 minutes	58 minutes	1 minutes	1 minutes
Transit	(A)	1667 m	6667 m	16667 m		
	(B)	5 minutes	20 minutes	50 minutes	5 minutes	5 minutes

A : Corridor Length

C : The access time to the corridor

B : Travel Time Required on the Corridor

D : the egress time from the corridor

4 The Simulation Trial Results

The model proposed in this study calculates how many commuters can work in CBD, when a single corridor is linked to CBD. Although the model assumes a rather simple structure, it reveals the following findings.

- 1) The maximum number of CBD employees is determined from the transportation capacity based on the headway of the mode or floor space quantity of CBD, and the size of the area of the suburbs is determined by the corridor length which depends on the commuting time upper limit with residential zones equally placed along the corridor. Therefore, though the largest number of commuters based on the commuting time upper limit may be equal, corridor length is different by transportation mode, and this in turn shows the different urban forms because the space quantity along the corridor is different. Corridor length and travel time for various commuting time upper limit for different modes are shown in Table 1. The increase in the commuting time upper limit brings about the increase in the corridor length, although it is not always linear since the access time in residential zone is included. Besides, the ratio between corridor lengths of both modes decreases with the commuting time upper limit increases.
- 2) In case of transit, the effect of the smallest headway of the transit works significantly, and the number of commuters depends on the transportation capacity constraint which depends on the smallest headway in all cases, and the CBD floor space constraint does not give any influence. The usage of CBD floor space is less than half and it is possible to introduce more transit routes in order to achieve higher floor area usage in CBD (see Table 2).
- 3) In case of automobile, road rate constraint is effective when the CBD road rate is comparatively low. The CBD floor space constraint functions as the road rate rises. This is shown in the following mechanism. (See Figure 2 and Table 2 for reference).
 - Increase in CBD road rate → Increase in CBD traffic lane numbers → Increase in transportation capacity.
 - Increase in CBD road rate → Decrease in CBD site area → Decrease in CBD floor space.
- 4) Automobile has lower transportation capacity than transit per traffic lane. Therefore, the transportation capacity can only be increased by increasing number of traffic lanes. Therefore, it is found for each CBD floor area ratio, the largest number of commuters and corresponding CBD road rate can be determined as is shown in Figure 3. This is explained from the discussion mentioned in the previous section. Thus it became apparent that the

situation with automobile is completely different from that of transit, because the former requires spaces for parking and travel, as Bruun et al. (Ref.6) indicated.

Table 2. Trial Result of Commuting Time Upper Limit of 30 Minutes

main calculation conditions				Transit				Car				
CBD Road Ratio(%)	CBD Floor area ratio(%)	headway of the transit(sec)	CBD floor space(m ²)	the maximum number of CBD employees(persons/hour)	generated constraint in CBD	operating the number(compositions/hour)	used proportion of the CBD floor space	the maximum number of CBD employees(persons/hour)	generated constraint in CBD	unilateral traffic-lane number	CBD Road Ratio(%)	used proportion of the CBD floor space
20	200	60	160000	3600	capacity	60.00	0.45	1714	road rate	2	14	0.429
30	200	60	140000	3600	capacity	60.00	0.514	3428	road rate	4	28	0.979
40	200	60	120000	3600	capacity	60.00	0.6	3000	floor space	4	28	1
50	200	60	100000	3600	capacity	60.00	0.72	2500	floor space	3	21	1
20	300	60	240000	3600	capacity	60.00	0.3	1714	road rate	2	14	0.286
30	300	60	210000	3600	capacity	60.00	0.343	3428	road rate	4	28	0.653
40	300	60	180000	3600	capacity	60.00	0.4	4285	road rate	5	35	0.952
50	300	60	150000	3600	capacity	60.00	0.48	3750	floor space	5	35	1
20	400	60	320000	3600	capacity	60.00	0.22	1714	road rate	2	14	0.214
30	400	60	280000	3600	capacity	60.00	0.257	3428	road rate	4	28	0.49
40	400	60	240000	3600	capacity	60.00	0.3	4285	road rate	5	35	0.714
50	400	60	200000	3600	capacity	60.00	0.36	5000	floor space	6	42	1
20	200	120	160000	1800	capacity	30	0.225	1714	road rate	2	14	0.429
30	200	120	140000	1800	capacity	30	0.257	3428	road rate	4	28	0.979
40	200	120	120000	1800	capacity	30	0.3	3000	floor space	4	28	1
50	200	120	100000	1800	capacity	30	0.36	2500	floor space	3	21	1
20	300	120	240000	1800	capacity	30	0.15	1714	road rate	2	14	0.286
30	300	120	210000	1800	capacity	30	0.171	3428	road rate	4	28	0.653
40	300	120	180000	1800	capacity	30	0.2	4285	road rate	5	35	0.952
50	300	120	150000	1800	capacity	30	0.24	3750	floor space	5	35	1

- 5) Next, the efficiency of the corridor space is examined. The corridor length for automobile is longer than that for transit because of higher speed and shorter access and egress time. Figure 4 shows the ratio of the maximum number of commuters to CBD for given corridor length. Though this index shows the transportation efficiency of the corridor in the form of the linear density, automobile does not exceed the value of transit. Therefore, the transportation efficiency of transit is clearly higher than that of automobile. Of course, transportation efficiency increases as required commuting time upper limit increases.
- 6) Finally, the traffic space area ratio of the corridor is examined. It is calculated as follows: (corridor length × number of traffic lanes for automobile mode) / (corridor length × number of tracks for transit mode). Here, width of a single lane or a track for both modes is assumed to be the same. To yield the maximum number of CBD commuters, automobile mode requires CBD road rate of 30 %. In case of commuting time upper limit of 30 minutes, traffic space ratio becomes 8.7 (see Figure 5). It is apparent that automobile needs much larger traffic space than transit. It also means that major traffic space is required along the corridor, as this index is a ratio of requirement quantity of the traffic space in the corridor part as well. As is the case above, the traffic space area ratio decreases as required upper limit time increases.

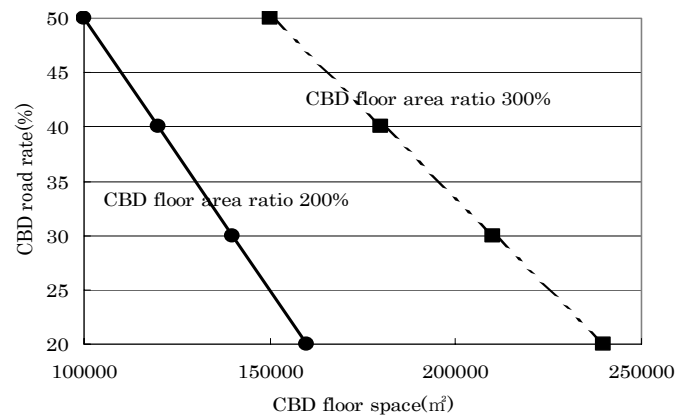


Figure 2. The Relationship between Floor Space and Road Rate in CBD

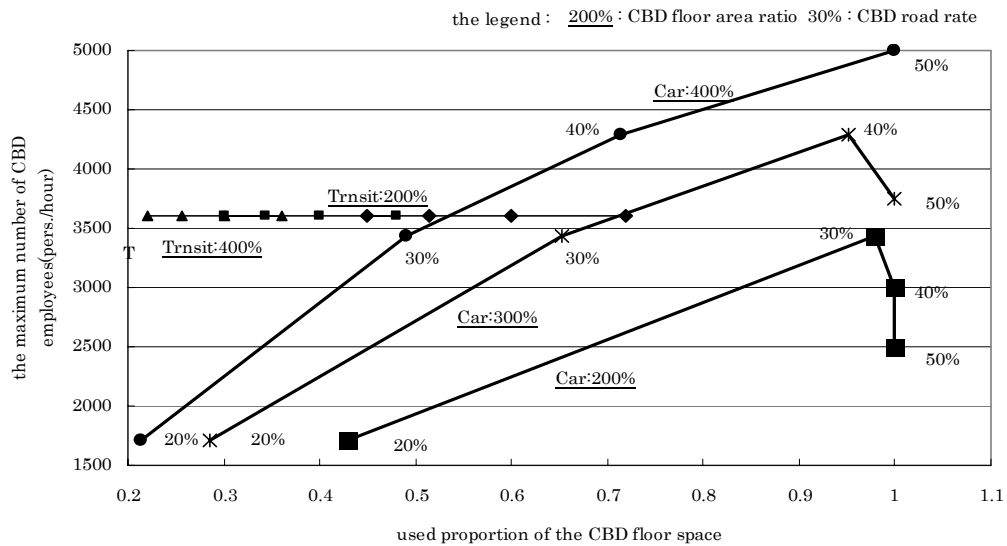


Figure 3. The Relationship between Maximum Number of CBD Employees and Proportion of the CBD Floor Space

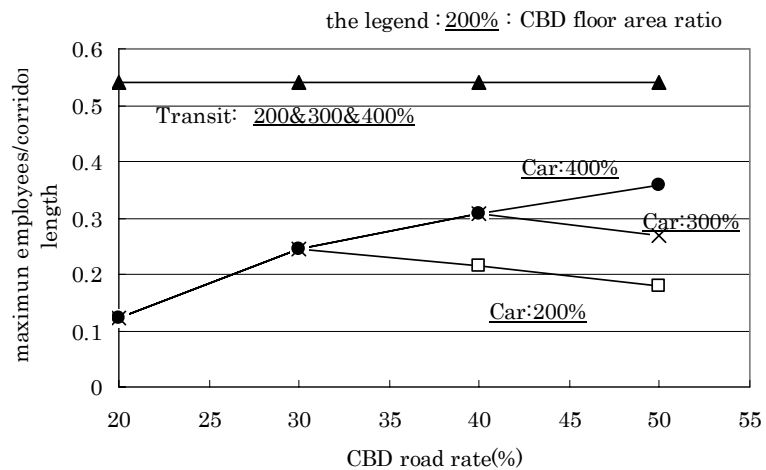


Figure 4. The Relationship between Maximum number of CBD Employees, Corridor Length and CBD Road Rate

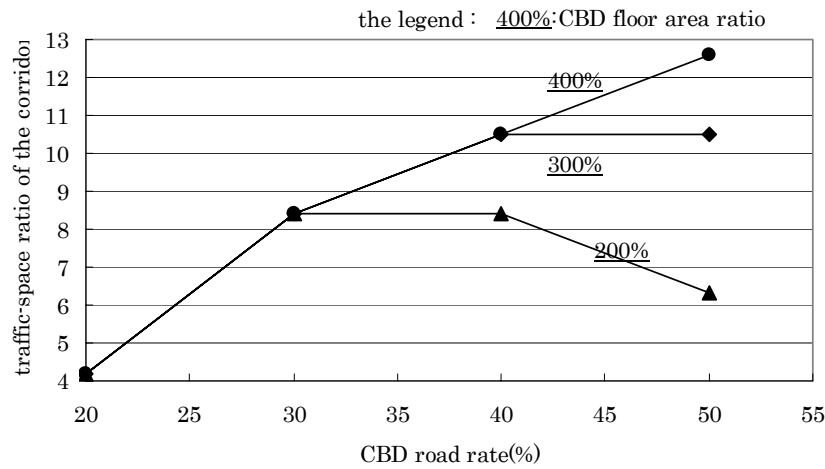


Figure 5. The Relationship between Traffic Space Ratio and CBD Road Rate

5 Conclusion

In this study, we tried to propose an urban land use model that can compare between automobile-oriented and transit-oriented cities, and clarify the difference between city forms by transportation modes. The model proposed here is a simple simulation model, which allocates people who commute to CBD from residential zones along transportation corridor starting from the zones closest to CBD then continue to allocate in the subsequent adjacent zones until the maximum number of CBD employees are reached.

In the experimental simulations, the transportation demand is assumed to be equal to the capacity. Therefore, although the relation between transportation capacity and commuting time upper limit was independent each other, it is clearly shown that automobiles need much more traffic space in comparison with the transit as is shown by the proposed traffic space ratio both in CBD and along the corridor. The traffic space ratio value is 8.7 times larger than transit in the case of 30 % CBD road rate, which attracts maximum number of CBD employment almost similar to the case of transit. Meanwhile, for automobiles with high running speed and easiness of access and egress, the corridor length for automobile-oriented city has the value twice longer than transit-oriented city for the commuting time upper limit of 30 minutes. Using this model, it is possible to calculate the number of urban area residents by multiplying maximum number of CBD employment with household size for both modes. Therefore, it can be explained that the urban area that depends on the automobile results in low-density suburban sprawl.

In actual urban design, the relationship between automobile mode and transit mode would be examined by comparing constraints such as available floor space and number of traffic lanes in CBD and the amount of transport investment must be taken into consideration. As far as transit is concerned, it is possible to accommodate to existing situation because of the flexibility of transit capacity. However, in case of the automobile, the relation between maximum number of CBD employment, CBD floor area ratio and CBD road rate is much more complicated and it is difficult to secure the necessary number of traffic lanes. Therefore, it is difficult to design a city that solely depends on automobile. Careful and systematic planning is required including lowering the level of development in CBD.

6 REFERENCES

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